In-situ biasing of semiconducting NWs in transmission electron microscopy: doping quantification and contact formation

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Semiconducting nanowires (NWs) are widely studied because the properties that stem from their three-dimensional, nanoscale nature open new opportunities for device design. Yet, to allow successful device integration, the quality of the NW/metal contacts and the control of carrier concentration are of paramount importance. We describe different kinds of semiconducting NW devices fabricated on electron transparent Si3N4 membranes, and we show how in-situ electrical transmission electron microscopy (TEM) can contribute to the understanding of NW doping, surface charges and contact formation.

First, we demonstrate that state-of-the-art off-axis electron holography in combination with electrical in-situ biasing can be used to detect active dopants and surface charges quantitatively in a single ZnO NW. We have acquired series of holograms on a reverse biased Schottky contact on a ZnO NW and analyzed the depletion width in the NW as a function of the reverse bias. Comparison of the experimental data with 3D simulations indicates an n-type doping level of 1x10^{18} cm^{-3} and a negative surface charge around -2.5x10^{12} cm^{-2}. The surface charge results in a surface depletion to a depth of 36 nm, providing excellent agreement between the simulated thickness of the undepleted core and the active thickness observed in the experimental data. On the other hand, we also present an original approach to create an atomically abrupt contact with low electrical resistance on NWs of group IV (silicon and germanium) using a thermally-induced propagation reaction of Al and Cu in the extremities of a Ge NW. To understand and control the metal diffusion into the NW that creates a metallic phase, detailed characterization at atomic length scales is necessary to understand how the metal atoms diffuse and incorporate into the formed phase at the reaction front and how these parameters relate to the electrical properties of the same interface. We show in-situ phase propagation of a metal-semiconductor phase of Cu and Al in Ge NWs in the TEM while measuring the current through the device, and analyze the metal diffusion process using structural and chemical characterization.